THE EFFECT OF DISPLAY LIGHTING ON UNFROZEN PORK COLOR

by

CHING-YAU SIMON HUNG

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D.H. Kropf
Major Professor

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INTRODUCTION

Color, one of the first impressions a potential customer has of a food or meat product, affects whether a meat product will be purchased or not. Rejection of displayed meat products frequently is a result of product discoloration.

Supermarket lighting can affect customer choices, especially at the retail meat display case. Display lighting effects could result from: 1) temperature elevation at the meat surface, 2) a photochemical effect and/or 3) light rendition because of different spectral energy distribution (Kropf and Hunt, 1984).

The purpose of this study was to evaluate the effect of display lighting system on fresh pork longissimus color, both in oxygen permeable and vacuum packaging.

Chapter II

REVIEW OF LITERATURE

Factors Affecting Display Life of Pork

Temperature. Temperature has an important effect on display life of pork, because the gaseous environment in the package, oxygen consumption by muscles and muscle reducing capacity are all affected by temperature (MacDougall, 1982). Ramsbottom and Koonz (1941) noted that low storage temperature discourages enzyme activity, decreases oxidation, reduces desiccation and drip, and makes for less discoloration of meat. For every 10C rise in temperature, oxidation rates are doubled (Watts, 1954; Bratzler, 1955).

Discoloration is rapidly increased by higher storage temperature when comparing -1C to 5C (O'Keeffe and Hood, 1980 a, b). The higher the temperature, the faster the acceleration of autoxidation rate of oxymyoglobin (George and Stratmann, 1952 a,b; Brown and Mebine, 1969) because oxygen dissociates more rapidly from myoglobin, leading to faster autoxidation of deoxymyoglobin. Satterlee and Zachariah (1972) found that autoxidation rate of bovine, ovine and porcine oxymyoglobin increase strikingly with higher temperatures in the range of 10 to 35C, causing more rapid and greater discoloration at higher temperatures.

Snyder and Ayres (1961) and Brown and Dolev (1963) also found that temperature has a tremendous effect on oxidative reaction rates. Raising the temperature from 0C to 4C doubled the oxidative reaction rates. Brown and Mebine (1969) did a similar study of temperature effects on oxidative reaction rate, and noted 40 to 50 times faster rates at 22C than at -2C. Maximal oxidation of myoglobin to metmyoglobin occurs closer to the meat surface because of the increased surface temperature, decreased oxygen solubility (Brooks, 1929; Urbin and Wilson, 1958), occurrence of optimal pO_2 for myoglobin oxidation (Ledward, 1970), and increased oxygen utilizing systems in the meat (Urbin and Wilson, 1961; Snyder, 1964; Bendall, 1972). At lower temperatures, greater redness was found, mainly because slower discoloration is attributed to decreased respiratory activity, when Snyder (1964) compared storage temperatures of 6, 2 and -2C for fresh beef.

Large differences concerning the initial reducing activity of muscles were found at different temperatures. At 30C, less than one hour is needed to accomplish 50% metmyoglobin reduction. For the same metmyoglobin reduction rate, 7 hours is needed at 9C and 48 hr at 0C (Hutchins et al., 1967).

Packaging. Packaging protects meat from physical damage, microbial deterioration, chemical change (Mills

and Urbin, 1960) and evaporative weight loss (Taylor, 1982), but influences the meat's behavior by changing its environment. Dehydrated meat surfaces become dark and dull due to increased heme concentration and structural change, but myoglobin at dehydrated meat surfaces apparently oxidizes more slowly than at non-dehydrated meat (Brooks, 1938).

Mackinney et al. (1966) noted that physical characteristics of transparent packaging films including opaqueness, translucence, glossiness, matteness and the degree of wrinkling can affect the color of meat cuts. Packaging films differ in gas and moisture permeability and influence the behavior of meat. According to Satterlee and Hansmeyer (1974), many factors such as oxygen penetration, microbial growth, fat oxidation, the presence of flavin compounds and oxygen permeability of the film affect the pigment stability of intact meat.

Sacharow (1974) suggested that an oxygen permeable film [5000 ml $O_2/m_2/24hr/atm$ at 24C with 100% relative humidity (RH) inside the package and 52% RH outside] allow sufficient oxygenation for an attractive red color. Even films with very high oxygen permeability, such as PVC (polyvinylchloride), can prevent gases from passing through film rapidly enough, thus depleting the oxygen slightly in meat packages with a measurable accumulation of CO_2.

However, the aerobic spoilage bacteria still have

sufficient oxygen to grow, and the concentration of CO_2 is too low to extend display life. Under these oxygen conditions, the concentration of deoxymyoglobin is kept low and redness is retained because the surface layer of oxymyoglobin is thicker and covers the layer of brown metmyoglobin formed 4 to 5 mm below the surface at the point of sufficiently limited penetration of oxygen. Within 1 to 3 days, the layer of brown metmyoglobin begins to thicken, depending on temperature. It becomes visible as the layer of metmyoglobin moves sufficiently close to the surface of meat, and results in meat which is no longer attractive and is rejected by consumers (Taylor and MacDougall, 1973).

According to Pierson et al.(1970), the rate of metmyoglobin reduction is decreased if the time of aerobic exposure between fabrication and packaging is increased. They found little difference in final myoglobin state for beef semimembranosus retained under aerobic conditions for 2 or 6 hours prior to anaerobic packaging. A 24 hour aerobic period caused more metmyoglobin which remained longer while a 48 hour aerobic period resulted in greatly elevated and persistent metmyoglobin and a slow and incomplete conversion to reduced myoglobin. Extended aerobic exposure prior to anaerobic packaging allows too much oxygen to diffuse into the muscle and results in more favorable conditions for oxidation.

One of the most effective, and simplest ways of

extending display life of fresh meat is vacuum packaging (Dean and Ball, 1958). In order to prevent myoglobin autoxidation, meat cuts must be kept either at very low or at high oxygen tensions. The small volume of residual oxygen within the package is still actively consumed by tissue respiration within 2 or 3 days, so that less than 0.5% oxygen and more than 20% CO2 will accumulate in the vacuum package (Taylor, 1982) and ultimately deoxymyoglobin will form. Kropf (1980) claimed up to 21 days display life at 2C for vacuum packaged beef muscles.

Figure 1 shows the relationship of partial oxygen pressure to myoglobin chemical states. George and Stratmann (1952) determined the maximum rate of oxidation of myoglobin to occur when pO2 in meat is between 1 and 1.4 mm Hg. At 20 mm Hg, the oxidation rate levels off to a constant value. The pO2 of normal atmosphere is approximately 160 mm Hg.

INITIAL MICROBIAL COUNTS. Longree and Armbruster (1987) pointed out that many kinds of microorganisms were found on meat, including molds, yeasts, and bacteria of genera Achromobacter, Clostridium, Escherichia, Flavobacterium, Pseudomonas, Micrococcus, Salmonella, Sarcina, Staphylococcus, Streptococcus, Lactobacillus, Streptomyces, Leuconostoc, Proteus, Yersinia, and Campylobacter.

Walker (1980) noted that bacterial growth can cause

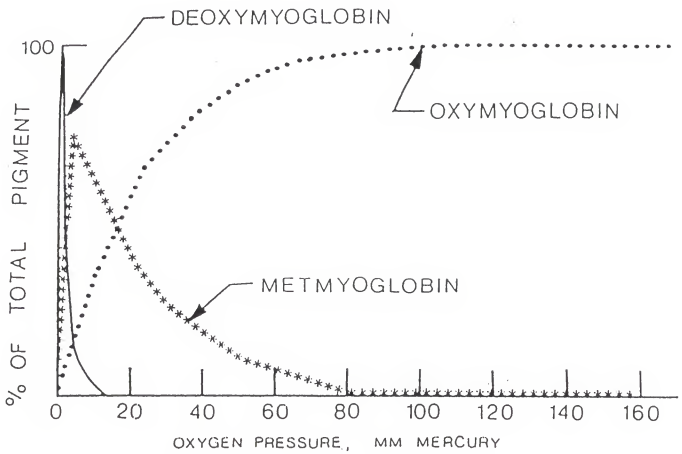

FIG. 1. The relationship of oxygen partial pressure to proportion of deoxymyoglobin, oxymyoglobin, and metmyoglobin.
From Forrest et al. (1975).

color deterioration of fresh meat. Higher temperature, sufficient water activity, proper gas environment and absence of inhibitors are factors that encourage bacterical growth.

Butler et al.(1953) observed that the main cause of initial discoloration and formation of metmyoglobin is decreased oxygen tension because of bacterial growth in packages of boneless beef steaks inoculated with Pseudomonas. Ledward et al.(1970) demonstrated that fresh beef stored at 0C and inoculated with large numbers of bacteria ($10^8/cm^2$) causes a depletion of surface oxygen, and therefore, induces the rapid conversion of surface oxymyoglobin to metmyoglobin, resulting in meat discoloration. Forrest et al.(1975) reported that bacteria will destroy myoglobin pigments as they are used for nutrients, or the bacteria can physically occlude the oxygen, resulting in oxidation of oxymyoglobin to metmyoglobin.

Some by-products of microbiological metabolism, such as hydrogen peroxide, are oxidizing agents, causing green and brown discoloration. Hydrogen sulfide production also can cause green discoloration on vacuum packaged meat because of the formation of sulfmyoglobin gradually found in high pH meat (> 6.0), caused by bacteria which can grow at low oxygen tensions (Breidenstein, 1982). Microorganisms can not strongly enhance discoloration of meats at lower bacterial counts. But, at high bacterial

counts, they cause oxidative conditions that encourage discoloration (Kropf and Hunt, 1984). Bacterial counts in meats, excluding ground meats, may be from 100 to 1 million per gram. Ground meat may contain up to 100 million per gram (Longree and Armbruster, 1987).

Light Effects on Meat Color

Heat. Brissey (1963), Santamaria (1970) and Kropf (1980) noted that display lighting resulted in the potential for increased temperature at the meat surface. Santamaria (1970) demonstrated a temperature elevation at the meat surface, resulting from either Incandescent or Deluxe Cool White fluorescent, of up to a maximum of 7 and 6C, respectively, with 300 foot candle lighting, compared with a sample retained in the dark.

Kropf (1980) stated deluxe fluorescent lamps radiate about 1/5 as much heat as incandescent lamps while reflective lamps with dichroic filters such as the GE Cool Beam radiate 1/3 as much heat as incandescent, for equal light intensities.

Lighting engineers estimated for each 10 foot candles of incandescent lighting the temperature could rise about 1C, at 70 cubic feet per minute air velocity. At the muscle surface, the warmer the temperature, the more rapid the muscle discoloration (Kropf and Hunt, 1984).

Photochemical. Radiant energy has the power to excite molecules at the meat surface, the so called photochemical effect. It can initiate or accelerate undesirable reactions (Kropf and Hunt, 1984). Bryce et al.(1946) found that riboflavin is sensitive to most wavelengths in the visible spectrum. Solberg and Franke (1971) hypothesized that the photochemical effect may excite molecules such as riboflavin and oxidize oxygenated heme pigments. Lynch et al.(1976) stated the same for the semiquinone of riboflavin generated by photoreduction.

Archer and Brandfield (1950) noted that strong absorption at some wavelengths caused more severe destruction of heme pigments. Kropf (1980) summarized reports that UV, blue and green, 350 to 580 nm light and yellow and orange all caused more rapid discoloration. Iverson (1985) found that using colored film to block out wavelengths below 550 nm decreased TBA values for vacuum packaged meat products during display.

Purified myoglobin has sharp, well-defined absorbancy peaks at 206nm and 408nm and has wider absorbancy peaks at 275, 504 and 603nm as reviewed by Kropf (1980). Oxymyoglobin has absorption peaks at about 545 and 582nm, reduced myoglobin has a wide absorption band maximum at 555nm (green) and metmyoglobin has absorption band maxima at 505 and about 630nm (Francis and Clydesdale,1975). High absorbancy wavelengths have greater potential for photochemical oxidation.

Giddings (1977) found that singlet oxygen is more reactive than the ground state. Triplet oxygen is a powerful oxidant of proteins and lipids. When exposed to light, singlet oxygen generated at oxygenated meat surfaces interacts to increase autoxidation.

Bala and Naumann (1977) claimed that light breaks the bond between iron and the negatively charged oxygen to produce the free radical oxygen, which catalyzes the chain oxidation of myoglobin and oxymyoglobin to metmyoglobin.

Color Rendition. Color rendition or spectral energy distribution is a concern for many business, such as supermarkets, art galleries, stores that sell clothing, carpeting and other items requiring color matching and/or appraisal (Kropf,1980).

Most light sources have their own characteristic mix of different wavelengths of visible light from violet, blue, green, yellow, orange and red. Those with a high proportion of light in the yellow part of the spectrum make objects under them more yellow, whereas those with a large proportion of red emission will make objects look redder (Kropf and Hunt, 1984).

Clark (1956) showed spectral reflectance patterns through the visible spectrum for four meat products (Figure 2) and noted that light sources with a closer fit to the reflectance pattern for any product or muscle will bring out the natural appearance of that product. The

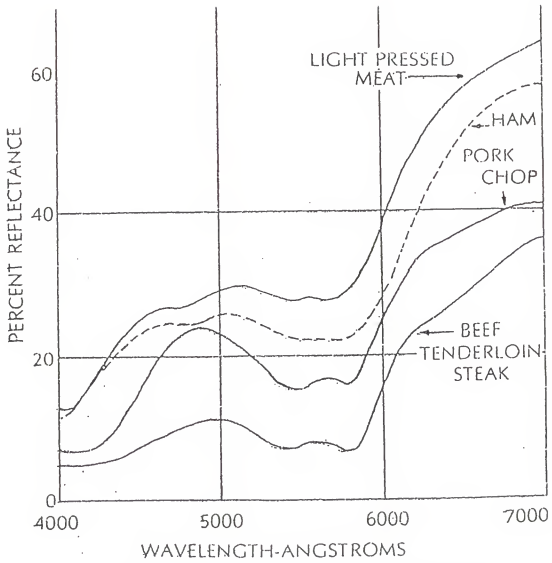

Figure 2. Spectral reflectance of several meat samples (Clark, 1956).

sources of meat light should be relatively rich in the red part of the spectrum.

Character of Different Lights. Fluorescent and incandescent are two general light sources of interest to the meat industry. Evans (1948) noted that fluorescent lights have a majority of short (cool) wavelengths which include some ultra-violet light, whereas incandescent lights have a majority of long (warm) wavelengths which include some infra-red wavelengths. Figure 3 shows the comparison of the spectral energy distribution of two light sources, standard cool white and deluxe cool white (Clark, 1956). Deluxe cool white is richer in the red and green parts of the spectrum and has less in violet, blue and yellow, whereas standard cool white emits more energy in the orange, yellow and green parts of the spectrum. Standard cool white is a more energy efficient light source than deluxe cool white. Figures 4 and 5 present the spectral energy distribution for two light sources, Incandescent Fluorescent and Deluxe Warm White, that were recomended by Kropf (1980) based on a frozen beef muscle display study. Both of them have a high proportion of red emission.

Table 1 shows the measured spectral energy distribution of nine light sources, giving the watts and percentage of the total wattage for six sections of the visible spectrum as well as ultraviolet and far-red. The first eight light sources are fluorescent. Grolux Wide

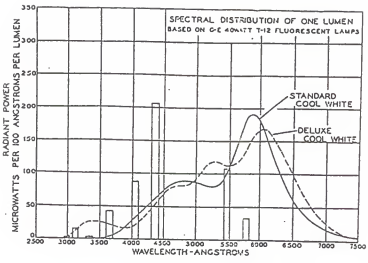

Figure 3. Spectral comparison of deluxe cool white and standard cool white fluorescent lamps (Clark, 1956).

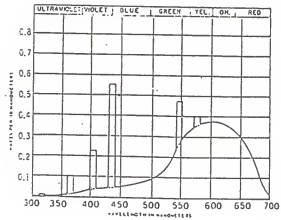

Figure 5. Warm White Deluxe F40WWX.

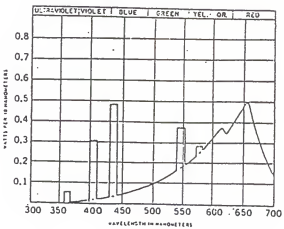

Figure 4. Incandescent Fluorescent F40IF.

Table 1 . Measured Spectral Energy Distribution of Nine Light Sources

	nm	Cool White		Deluxe Cool White		Deluxe Warm White		Natural		Soft White		Standard Gro-lux		Wide Spec Gro-lux		Incan. Fluores.		Incandes.	
		Watts	%	Watts	%	Watts	%	Watts	%	Watts	%	Watts	%	Watts	%	Watts	%	Watts	%
UV	<380	0.16	1.7	0.15	2.1	0.13	1.8	0.26	3.6	0.49	7.0	0.13	1.8	0.29	3.4	0.12	1.9	0.11	1.1
Violet	380-430	0.72	7.6	0.56	7.8	0.38	5.4	0.51	7.1	0.50	7.1	0.53	7.3	0.82	9.7	0.13	2.0	0.18	1.9
Blue	430-490	1.98	20.8	1.36	18.8	0.84	11.8	1.12	15.5	1.32	18.7	1.73	23.8	1.32	15.6	0.45	7.0	0.53	5.5
Green	490-560	2.35	24.7	1.73	24.0	1.68	23.7	1.54	21.3	1.47	20.9	1.10	15.1	1.18	14.0	1.04	16.2	1.25	12.9
Yellow	560-590	1.74	18.3	0.86	11.9	1.09	15.4	0.79	10.9	0.86	12.2	0.17	2.3	0.85	10.1	0.76	11.8	0.78	8.1
Orange	590-630	1.69	17.8	1.20	16.6	1.46	20.6	1.18	16.3	1.34	19.0	0.55	7.6	1.40	16.6	1.23	19.2	1.30	13.5
Red	630-700	0.81	8.5	1.36	18.8	1.52	21.4	1.83	25.3	1.07	15.2	3.03	41.6	2.00	23.7	2.21	34.4	2.91	30.1
Total		9.52		7.22		7.10		7.23		7.05		7.28		8.45		6.42		9.66	
Far Red		0.07	0.7									0.04	0.5	0.59	7.0	0.48	7.2	2.60	26.9

Kropf (1980).

Spectrum is relatively high in blue whereas Incandescent Fluorescent and Incandescent is low in blue. Incandescent is low in green whereas Cool White, Deluxe Cool White and Deluxe Warm White are high. Extremes in yellow were shown by Cool White at 18.3% of total wattage and Standard Grolux at 2.3%. Red emission ranged from 8.5% for Cool White to 41.6% for Standard Grolux and these two light sources are considered, respectively, to provide very poor rendition for beef muscle and to make them look misleadingly red. Providing good color rendition of lights and their percentage of redness are Incandescent Fluorescent (34.4), Incandescent (30.1), Natural (25.3), Grolux Wide Spectrum (23.7) and Deluxe Warm White (21.4).

Tuma et al.(1973) noted that Cool White results in a very blue, discolored appearance of muscle and does not have enough red emission to bring out the natural color. This lighting puts red meat products under a disadvantage in the supermarket. However, much general store lighting is Cool White. Soft White and Deluxe Cool White also are not ideal sources for meat display, but Deluxe Cool White is often used for meat case lighting, and its major advantage is the white color imparted to fat. Deluxe Warm White and Incandescent Fluorescent, which seem good in color emission balance for muscle, cause slightly yellow fat color.

Sleper and Hunt (1982) studied the effects of 18 different light sources on rib steak appearance.

Incandescent and Incandescent Fluorescent resulted in a more yellow lean than 12 sources. Standard Grolux fluorescent resulted in a redder color than all other sources, whereas Daylight and Cool White caused a bluer color than 11 other sources.

Calkins et al. (1986) studied the effects of lighting type on fresh pork color under delux cool white (DCW), Surlyn coated cool white (CWSC), warm white (WW) fluorescent and cool flood incandescent (CF) lights. They stated that light types CF and DCW present the most desirable color rendition. However, CF light can elevate the surface temperature of pork chops, causing greater microbial growth, resulting in darker meat.

Factors Affecting Pork Color

Muscle. All muscles contain red and white muscle fibers, although some have divided these into a larger number of fiber types. The gross visualization of a muscle as red or white depends on the proportion of the type of muscle fibers. Those muscles with relatively high proportions (30 to 40%) of red fibers contain higher myoglobin and appear darker red in color. Some muscles are classified as white muscles since they contain less than 30% red fibers, while others with 40% or more of red fibers are called red muscles (Beecher et al.,1965).

Quality - PSE, Normal and DFD. A normal pH decline pattern gradually decreases from a pH of 7 to pH 5.6 to 5.7 within 6 to 8 hours postmortem. It reaches an ultimate pH of 5.3 to 5.7 at approximately 24 hours postmortem. In some animals with a dark, firm, dry (DFD) muscle, the pH drops only a few tenths of a unit during the first hour after slaughter. Then it remains stable at a relatively high level, developing an ultimate pH of 6.5 to 6.8. In other animals having pale, soft, exudative (PSE) muscle, the pH drops rapidly to pH 5.4 to 5.5 during the first hour after slaughter, giving an ultimate pH of 5.3 to 5.6 (Forrest et al., 1975).

PSE muscles result from rapid glycolysis of glycogen, (Romans and Ziegler, 1977), which causes the accumulation of lactic acid (pH drop) after slaughter. The rapid development of an acidic condition in the muscle while still at a high carcass temperature, for example, pH 6.0 and 35C (Locker and Hagyard, 1963), causes denaturation of contractile and/or sarcoplasmic protein. If the sarcoplasmic proteins are denatured, they may adsorb to contractile proteins, thus modifying the physical properties of the contractile proteins. Because of the denaturation of the contractile proteins, the ability of the contractile proteins to bind water is decreased (Fennema, 1985). With the shrunken fibers, most light striking the muscle surface is reflected by extracellular water. The visual color intensity is, therefore, greatly

reduced. The pigment of PSE muscle might also appear light in color either because of a possible denaturation during the early postmortom period, or because of a direct effect of low pH on light reflecting properties of the pigments (Forrest et al., 1975).

A DFD muscle can occur from animals with a degree of stress susceptibility, if they have survived a stress of sufficient duration to deplete their glycogen reserves, such as that associated with fatigue, exercise, fasting, excitement, fighting, restraint, electrical shock, or adrenalin injection. When stress susceptible animals are stressed, they begin to break down glycogen and form lactic acid in the muscle. If those animals are slaughtered before more glycogen is stored in muscle and after the lactic acid has been removed from the muscle by the circulatory system, the muscle will be DFD. The high water binding capacity of these muscles causes the fibers to be more turgid and they absorb most of the light striking the meat surface, giving a dark appearance (Krzywicki, 1979). The high-pH meat may be dark also due to the continuance of mitochondrial activity for a longer than normal period of time. Active mitochondria might compete with myoglobin for oxygen at the surface of the meat, resulting in less formation of bright red oxymyoglobin formed (Ashmore et al., 1972).

Stress resistant animals are able to maintain normal temperature and homeostatic conditions even under

relatively severe stress, and thus have normal muscle quality (Forrest et al., 1975).

Pigment Content. The heme pigments, myoglobin and hemoglobin, are the most important contributors to meat color. They absorb certain wavelengths of light and reflect others.

Myoglobin accounts for about 90% of the total heme pigment, whereas hemoglobin accounts for the other 10% (Shenk et al., 1934; Satterlee and Snyder, 1969; Price and Schweigert, 1971; Clydesdale and Francis, 1976). Very small contributions to muscle color may be made by flavins, vitamin B_{12}, cytochomes, catalase (Forrest et al., 1975), and bilins (Mackinney and Little, 1962).

Hemoglobin and myoglobin both have the same prosthetic groups, a heme and an iron porphyrin. However, the myoglobin molecule is one-fourth as large as the hemoglobin molecule. Myoglobin consists of a single heme compound with a molecular weight of about 17,800 while the hemoglobin molecule contains four hemes and has a molecular weight of about 68,000 (Watts, 1954; Stryer, 1975; Mackinney and Little, 1962; Price and Schweiger, 1971). The heme compound of the pigment is especially interesting because the color of meat is partially dependent on the chemical state (oxidation state) of the iron within the heme ring.

Pigment content varies with species, breed, muscle,

age, sex, diet, and physical activity (Forrest et al., 1975; Lawrie, 1966). Species differences are apparent when the light color of pork is compared with the bright red color of beef. The longissimus muscle of Large White swine has more myoglobin than the muscle from Landrace hogs (Lawrie, 1974). The low myoglobin content in the breast muscles of chicken contrasts with the higher myoglobin level in dark muscles of the leg and thigh. The pale muscles of veal carcasses are indicative of the lower myoglobin content of immature beef animals which have received a very low iron diet. Romans et al.(1965) stated that myoglobin concentrations are higher in more mature beef carcasses, and Lawrie (1974) found pork longissimus dorsi of 5, 6 and 7 month old swine to have 0.30, 0.38 and 0.44 mg/g myoglobin, respectively. The intact male has more myoglobin than females or castrates at comparable ages. A diet low in iron will result in less myoglobin formed in muscles. Game animals have darker muscles than those of domestic animals partially due to the effect of a higher level of physical activity (Forrest et al., 1975; Lawrie, 1966). Myoglobin content for different species is 2.0 to 5.0 mg/g wet weight in beef (Hunt and Hedrick, 1977) ; 4.0 to 7.0 mg/g in lamb (Ledward and Shorthose, 1971) ; and 2.5 to 7.0 mg/g in pork (Topel el al., 1966). Livingston and Brown (1981) found that genetic and certain environmental factors may also affect pigment content. Hart (1961) showed lower myoglobin content in porcine

pale, soft and exudative muscle. Vaughan and Pace (1956) claimed that myoglobin levels are higher for animals that become accustomed to high altitudes. When animals are exposed to constant temperature, myoglobin in porcine skeletal muscle may reach higher levels than those subjected to fluctuating temperature from moderate to high humidity (Thomas and Judge, 1970).

Meat Color Measurements

Meat color measurements involve human visual appraisal and instrumental analysis. Both are associated with the chemistry of myoglobin.

Although the human eye evaluates the total impression of a meat surface (Coon,1982), visual scoring may not be repeatable from day to day, and is dependent on individual ability to perceive color differences. This ability is influenced by personal preference, lighting and visual deficiencies of the eye. For improving panel consistency and effectiveness, suitable pictorial standards and scoring scales are helpful (Desroisier, 1954; Hunt and Kropf, 1985b).

Hunt (1980), and Hunt and Kropf (1985a) compiled a listing of scoring scales, most of which are descriptive and involve averaging the color on the meat surface. The use of which pictorial color standard to use is not arbitrary, but depends on the color variations and objectives of the research study.

Hunt and Kropf (1985b) summarized some recommendations of visual appraisal:

1. conscientiously match the scoring scale descriptions to the objectives of the study and color variations anticipated,

2. conduct a pretrial study to help elucidate the spectrum of colors or discolorations unique to the study,

3. use colored pictures or three-dimentional aids when possible for training and panel reference,

4. consider use of more objective visual methods such as measuring percentage areas of discoloration with a grid or planimeter,

5. place less reliance on scales that infer "averaging" of color over the entire cut surface when "worst point" scoring may more closely reflect consumer discrimination patterns.

To overcome the disadvantages of the human eye in color perception and to meet the need for objectivity in recording colors, various instruments have been developed (Chichester, 1954; Esau, 1958).

Numerous color systems (e.g., Hunter, CIE-tristimulus, Munsell) have been constructed for establishing meat color standards, selection criteria, and precise descriptions of consumer or other evaluators responses to meat color. Such descriptions have not been widely used to follow subtle color changes in meat research because they provide no information about

specific causes of color deterioration. However, these systems provide important information concerning how color is perceived (Hunt, 1980).

Reflectance and transmission spectrophotometry offer an instrumental approach which estimates myoglobin properties, and consequently provides useful information relative to treatment effects on pigment stability. Repeated readings obtainable on the same meat surface are an important advantage of using reflectance spectrophotometry during the time of display and storage studies without changing the relationship between meat and film.

One photon of light absorbed by one electron in one molecule of a compound is the basic principle of the spectrophotometer, therefore the number of photons absorbed is proportional to the concentration of the compound being measured (Adams, 1982).

The spectrophotometer can be used for qualitative analysis. The points of peak and minimal absorption are noted and the sample is scanned over a broad range of wavelengths. Based on the Beer-Lambert law, reflectance data can also be used for quantitative analysis. The absorption of the sample is measured at only one wavelength (Adams, 1982). According to the Beer-Lambert law, the amount of incident light absorbed at a single wavelength is proportional to the number of absorbing molecules in the solution (Weast et al., 1983).

Pigment extraction and transmission or absorption spectrophotometry, giving sharp and well-defined peaks, are the methods of choice to quantify the amount of myoglobin extractable from meat. But the method destroys the sample and provides no reliable information on pigment chemical form due to sample oxygenation or oxidation during the extraction process. The proportions of oxymyoglobin (MbO) and metmyoglobin (MMb) are often overestimated while deoxymyoglobin (Mb) is underestimated. Because pigment forms change with oxygen partial pressures, depth of sampling is another serious problem of extraction techniques (Hunt,1980; Kropf et al., 1984). However, Krzywicki (1982) found that an extraction method under low temperature and pH control could minimize pigment form interaction.

Meat color measurements using reflectance spectrophotometry are combined with mathematical manipulation of data from selected wavelengths. Estimation of Mb, MbO and MMb is essential for basic studies of pigment stability. Reflectance scans (Figure 6) for Mb, MbO, and MMb cross at various wavelengths that are isobestic for any two of the myoglobin forms measured, so this wavelength should be useful for estimating the third myoglobin form. Values are converted to K/S (absorption coefficient / scattering coefficient) (Judd and Wyszecki, 1963). Wavelength ratios are put into equations requiring a standard value for 0% and 100% of

the calculated pigment form.

The wavelength of 525 nm is isobestic for all three pigment forms. Consequently, reflectance at 525 nm is often a denominator for ratios of many color calculations because it is related to total myoglobin concentration regardless of the pigment form. Reflectance at wavelengths 474 and 572 nm can be used to estimate percent Mb and MMb, respectively, when divided by reflectance at wavelength 525 nm. Since 572 nm is an isobestic wavelength for both Mb and MbO, 474 nm for both MMb and MbO, and 525 nm is an isobestic piont for Mb, MbO, and MMb, a ratio of reflectances at 572/525 and 474/525 (each reflectance converted to K/S for linearity) could be related to percentage of MMb and Mb, respectively, on the meat surface (Snyder, 1964; Steward et al., 1965; Krzywicki, 1979). The percentage of oxymyoglobin is estimated by the difference from 100%.

Since 630 nm is an absorption maxima for MMb while MbO absorption is minimal, and 580 nm is an absorption maxima for MbO, the reflectance differences between wavelengths 630 nm and 580 nm or the ratio of 630nm / 580nm have been useful in experiments where redness differences exist or develop (Booren et al., 1981a, b; Paterson et al., 1984). Using 730 nm to adjust for reflectance of pigment-free meat many help correct for muscle pH, structure and pigment differences between samples (Krzywicki, 1979).

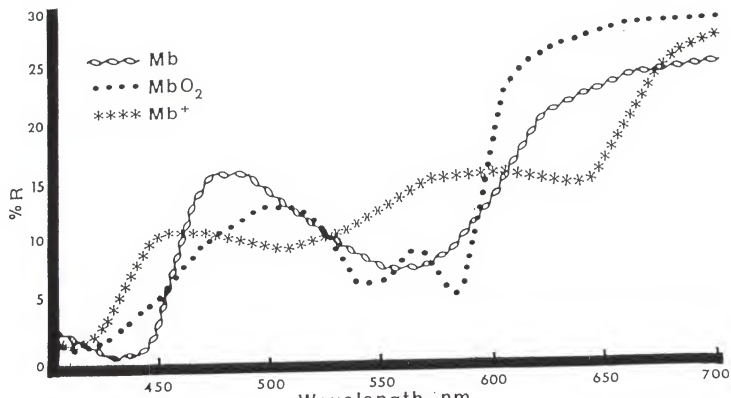

FIG 6. Reflectance spectra of deoxymyoglobin (Mb), oxymyoglobin (MbO_2) and metmyoglobin (Mb^+).
From Snyder (1965).

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Chapter III

EFFECT OF DISPLAY LIGHTING ON UNFROZEN PORK COLOR

INTRODUCTION

Color is the first impression of meat quality (Mackinney and Little, 1962). Color of meat cuts has both a psycholgical and a real effect on consumers. This psychological effect of color causes consumers to have a positive or negative response while the real effect indicates overall quality as affected by storage or display time, temperature, and how the product was handled (Hiner, 1954). Displayed meat products are often rejected because of discoloration.

Supermarket lighting can put meat products under considerable stress and can also affect customer visual choices. Display lighting effects could result from: 1) temperature elevation at the meat surface, 2) a photochemical effect and/or 3) meat color rendition due to different spectral energy distribution patterns (Kropf, 1980).

Little information is found in the literature on effects of lighting on unfrozen pork color. The objective of this research was to evaluate the effect of display lighting system on unfrozen pork longissimus color, packaged in both oxygen permeable and impermeable films.

MATERIALS AND METHODS

Fourteen chops (2.0 cm thick) were cut from each of seven loins and randomly assigned to light type. Seven lighting systems, Natural (N), Grolux Wide Spectrum (GWS), NAFA, Incandescent Fluorescent (IF), Deluxe Warm White (DWW), Deluxe Cool White (DCW) and Cool White (CW) were compared under similated retail conditions, but with continuous lighting (24 hr/d). Both impermeable (vacuum) and polyvinylchloride (PVC) packages were used.

Display Conditions

Chops assigned to the PVC packaging treatment were placed on styrofoam trays and wrapped in gas permeable PVC film (5000 ml O2/m2/24 hr @ 23C). The others were vacuum packaged in oxygen barrier film (<30 ml O2/M2/24 hr @ 23C). Chops were displayed under 1076 lux (100 foot candles) at 2 to 3 C.

Visual Evaluation

Visual evaluation of coded chops was conducted by a 4-member, experienced panel, for the overall color of longissimus muscle using the KSU 5-point descriptive scale to the nearest 0.5 (1 = very bright pink, 2 = bright pink, 3 = slightly dark pink, 4 = dark pink or brown, 5 = very dark pink or brown) at 0, 1, 3 and 5 days of PVC packaged display (Kropf et al., 1971). The visual scale for

vacuum packaged product (1 = bright purplish pink, 2 = purplish pink, 3 = slightly brownish pink, 4 = brownish pink, 5 = brown) was applied at 0, 7, 14 and 21 d vacuum-packaged display. The visual evaluation for each chop was conducted both under the display light, also under a common light (Natural light), to try to determine if differences, if any, were from a photochemical effect or light rendition.

HunterLab Values.

Each chop was scanned in two different locations for Hunter L, a, b and L*, a*, b* (CIE) values using illuminant A (ILL A, incandescent lamp) and illuminant C (ILL C, noon-daylight) with a HunterLab D-54 spectrophotometer. L, a and b values define three dimensional points in the color spectrum (Appendix I). The "L" value measures brightness to darkness, 0 (black) to 100 (white); the "a" value represents redness (positive values) and greenness (negative values); the "b" value defines the degree of yellowness (positive values) and blueness (negative values). Chops were read while overwrapped in packaging film. The optical port was kept clean periodically and large fat in the chops were avoided in choosing areas to scan.

Spectrophotometric Reflectance

Percentage reflectance at selected wavelengths, 474,

525, 572, 580, 610 and 630 nm, was measured spectrophotometrically at two different locations with a HunterLab D-54 spectrophotometer.

Ratios of K/S values at 572 nm/525 nm and 474 nm/525 nm were calculated to determine percentage MMb (metmyoglobin) and percentage Mb (deoxymyoglobin), respectively. MbO (oxymyoglobin) was obtained by difference. Reflectance values were transformed to K/S ratios using Kubelka-Munk's equation [$K/S = (1-R)^2/2R$)] to determine the ratio of the absorption and scattering coefficients (Francis and Clydesdale,1975). The constants used in pigment calculations were 0.957 for 0% Mb and 0.543 for 100% Mb (Snyder and Armstrong, 1967); 1.40 for 0% MMb and 0.56 for 100% MMb (Stewart et al., 1965). All were determined for beef samples. The equations used were:

%MMb = (K/S 572/525(0%MMb) - K/S 572/525 (sample)) * 100 /
(K/S 572/525 (0% MMb) - K/S 572/525 (100% MMb))

%Mb = (K/S 474/525 (0% Mb) - K/S 474/525 (sample)) * 100 /
(K/S 474/525 (0% Mb) - K/S 474/525 (100% Mb))

%MbO = 100% - %Mb - %MMb

The differences between percentage reflectance at 610 and 580 (% R 610 - % R 580), and 630 and 580 nm (% R 630 - % R 580) were calculated to indicate muscle redness; the higher the number, the brighter red the sample.

Oxidative Rancidity Test

Oxidative rancidity was expressed as ug of malonaldehyde per 5 ml of filtrate (which represented 1 g of sample) or mg of malonaldehyde per Kg of sample, as measured by the thiobarbituric acid (TBA) test using the extraction method of Witte et al. (1970) modified by Kuntapanit (1978). TBA was measured only at day 5 of display for PVC packaged pork. TBA analysis was run in duplicate on each chop representing each light treatment. The absorbance of TBA values was determined at 529.5 nm with a Gilford spectrophotometer (Gilford Instrument Lab. Inc., OH).

Statistical Analysis

Data were analyzed by analysis of variance and means were compared by Least Significant Difference (LSD) test (Steel and Torrie, 1980). Data analysis were done with the Statistical Analysis System (SAS) program (SAS Institute, 1982).

RESULTS AND DISCUSSION

Visual scores under display light for PVC packaged pork longissimus were low at the beginning of the display indicating bright pink color and scores increased over time of display for all seven lighting systems (Table 1). A light effect ($P < 0.01$) was found at day 0, 1, 3 and 5. When scored under display light chops, displayed under NAFA lighting had brighter pink color than all other lighting systems except Grolux Wide Spectrum, while those displayed under CW had darker color from day 0 to day 5. No differences ($P > 0.05$) were found when all chops were scored under the same light (Natural, Table 2). The differences between scores under display lighting and Natural lighting may be because of the effect of color rendition when scored under different display lights.

Lighting system affected color score of vacuum packaged chops ($P < 0.01$) at day 0, 7, 14 and 21 (Table 3). Visual scores of vacuum packaged pork under NAFA lighting were lower (brighter purplish pink) than all other light sources except GWS, while visual scores under CW lighting were higher (darker) than others throughout display. Pork longissimus displayed under CW light type had shown brownish pink color (score = 4) at day 14. This could cause consumer rejection and the meat likely was unsaleable. MacDougall (1982) indicated that consumer discrimination begins at 20% MMb while meat surfaces

appear brown with 40% MMb. A slight difference between lighting types ($P < 0.05$) was noted at day 0 for vacuum packaged pork visually scored under Natural lighting (Table 4). At day 14, an effect ($P < 0.01$) was found which may be due to long term display.

Watts (1954) reported that fresh meats are not materially discolored by display lighting during a period of three days, but longer display may cause discoloration mainly because of microbial development.

No different effects ($P > 0.05$) from lighting systems were observed for Hunter L, a and b values with ILL A (Table 5) and ILL C (Table 6), and for Hunter L*,a* and b* (CIE) values with ILL A (Table 7) and ILL C (Table 8) for PVC packaged pork. Furthermore, light types had no effect ($P > 0.05$) on the redness (% R 630 - % R 580 and % R 610 - % R 580) of chops (Table 9), and no effect ($P > 0.05$) was noted on percentage of MbO and MMb (Table 10) of PVC packaged pork, although the redness of Hunter a value (ILL A, Table 5 and ILL C,Table 6), and Hunter a* (CIE) value of ILL A (Table 7) and ILL C (Table 8), and % R 610 - % R 580 and % R 630 - %R580 (Table 9) of spectrophotometric measurements seemed to decrease with display time but was not statistically analyzed. Also, no statistical differences ($P > 0.05$) existed among lighting systems for TBA value (Table 11). These results would indicate no photochemical effect of display lighting on PVC packaged pork color or development of oxidative

rancidity.

On vacuum packaged pork, no effect ($P > 0.05$) of lighting systems was noted for Hunter L, a and b values (ILL A and ILL C) and Hunter L*, a*, b* (CIE) values (ILL A and ILL C) as shown in tables 12, 13, 14 and 15, respectively. Redness as shown by % R 610 - % R 580 and % R 630 - % R 580 (Table 16) and percentage MMb and Mb of vacuum packaged pork (Table 17) were not affected ($P > 0.05$) by lighting treatments. The percent MMb at the surface of the longissimus muscle calculated according to Stewart et al. (1965) shows no differences among lighting systems and is not high enough to cause consumer rejection at any display time. Greene et al. (1971) indicated that 30 to 40% MMb is needed for rejection by a consumer because of discoloration of meat, although MacDougall (1982) stated that consumer discrimination begins at 20% MMb.

Ramsbottom et al. (1951) and Kraft and Ayres (1954) reported no difference between the color of fresh meat exposed to light and stored in the dark. Marriott et al. (1967) reported discoloration of fresh beef under lighting. Although there are conflicting reports, Goll (1984) found no light type differences among Surlyn coated Cool White, Deluxe Cool White and Warm White when visually evaluated under these display lights. Our work supports the finding of no apparent photochemical effect of different light sources. The effect noted on pork color

in our study likely is due to light rendition because of different spectral energy distribution.

A set of samples run in dark parallel to the light exposed samples might be a good control for future studies. This would detect any photochemical effects above the rate of discoloration normally expected.

Clark (1956) stated that the best and most honest light sources are those that emit the various visible wavelengths from violet through red at a level close to the reflecting properties of meat products. According to table 2 and 4, we recommend the light systems NAFA, GWS (Grolux Wide Spectrum) and N (Natural light) as better lighting sources for display lighting.

CONCLUSIONS

The objective of this experiment was to determine the effects of display lighting on unfrozen pork longissimus color, packaged in gas permeable film (PVC) and vacuum packaged in oxygen barrier film. In this study, we conclude: 1) no photochemical effect was found from seven lighting systems on pork longissimus, 2) the variation of perceived color was primarily due to light rendition resulting from different spectral energy distribution patterns, 3) the lighting systems NAFA, Grolux Wide Spectrum and Natural light are recommended as better light sources for retail display, and 4) Cool White is not recommended as a light source for retail display.

Table 1. Display lighting effects on PVC packaged pork longissimus visual color score[a] under display light.

Lighting system[b]	Display day 0	1	3	5
N	1.76[d]	2.11[d]	2.43[def]	2.79[fg]
GWS	1.69[de]	1.80[fg]	2.32[ef]	2.63[fg]
NAFA	1.55[e]	1.64[g]	2.25[f]	2.46[g]
IF	1.83[d]	1.88[ef]	2.54[de]	2.82[def]
DWW	1.82[d]	2.00[de]	2.57[d]	3.02[d]
DCW	1.82[d]	2.09[d]	2.54[de]	2.88[de]
CW	2.26[c]	2.59[c]	3.21[c]	3.63[c]
Prob. <	0.01	0.01	0.01	0.01

[a]Visual score: 1 = very bright pink, 3 = sl. dark pink, 5 = very dark pink or brown.

[b]Lighting system: N = GE Natural, GWS = Sylvania Grolux Wide Spectrum, IF = Sylvania Incandescent Fluorescent, DWW = GE Deluxe Warm White, DCW = GE Deluxe Cool White and CW = GE Cool White

[c-g]Means in a column with the same superscript letter are not different ($P > 0.05$).

Table 2. Display lighting effects on PVC packaged pork longissimus visual color score[a] under GE Natural lighting.

Lighting system[b]	Display day			
	0	1	3	5
N	1.75	1.98	2.48	2.77
GWS	1.80	1.91	2.45	2.79
NAFA	1.83	1.91	2.54	2.89
IF	1.80	1.93	2.45	2.86
DWW	1.78	1.96	2.54	2.89
DCW	1.79	1.98	2.54	2.86
CW	1.80	2.07	2.55	2.91
Prob.	0.81	0.38	0.79	0.39

[a]Visual score: 1 = very bright pink, 3 = sl. dark pink, 5 = very dark pink or brown.
No differences due to lighting system. ($P > 0.05$).

[b]See table 1.

Table 3. Display lighting effects on vacuum packaged pork longissimus visual color score[a] under display light.

Lighting system[b]	Display day			
	0	7	14	21
N	1.54^{de}	2.36^{ef}	2.73^{ef}	3.04^{d}
GWS	1.49^{ef}	2.23^{f}	2.55^{f}	2.96^{d}
NAFA	1.30^{f}	1.93^{g}	2.27^{g}	2.50^{e}
IF	1.67^{de}	2.54^{de}	2.82^{e}	2.92^{d}
DWW	1.65^{de}	2.57^{d}	2.93^{e}	2.92^{d}
DCW	1.74^{d}	2.57^{d}	3.20^{d}	2.96^{d}
CW	2.20^{c}	3.48^{c}	4.00^{c}	4.00^{c}
Prob. <	0.01	0.01	0.01	0.01

[a]Visual Score: 1 = bright purplish pink, 3 = sl. brownish pink, 5 = brown.

[b]See Table 1.

[c-g]Means in a column with the same subscript letter are not different (P > 0.05).

[h]Day 21 data, 3 samples only.

Table 4. Display lighting effects on vacuum packaged pork longissimus visual color score[a] under GE natural lighing.

Lighting system[b]	Display day			
	0	7	14	21[f]
N	1.54[c]	2.32	2.70[de]	3.00[d]
GWS	1.52[cd]	2.45	2.60[e]	2.96[d]
NAFA	1.53[cd]	2.41	2.62[e]	2.96[d]
IF	1.45[de]	2.39	2.77[cd]	2.92[d]
DWW	1.40[e]	2.39	2.83[cd]	3.00[d]
DCW	1.45[cde]	2.34	2.81[cd]	3.21[c]
CW	1.47[cde]	2.48	2.84[c]	3.25[c]
Prob. <	0.04	0.58	0.01	0.02

[a]Visual Score: 1 = bright purplish pink, 3 = sl. brownish pink, 5 = brown.

[b]See Table 1.

[c-e]Means in a column with the same subscript letter are not different (P > 0.05).

[f]Day 21 data, 3 samples only.

Table 5. Display lighting effects on PVC packaged pork longissimus L, a and b value, Illuminant A.

Lighting	Hunter	Display day			
system[a]	value	0	1	3	5
N	L	43.0	43.1	41.8	44.7
	a	14.9	13.7	12.6	10.6
	b	4.1	3.9	3.8	3.6
GWS	L	43.1	42.9	43.3	44.0
	a	13.5	12.7	12.1	10.3
	b	3.8	3.5	3.8	3.3
NAFA	L	42.5	43.6	42.8	43.6
	a	13.9	12.7	11.6	10.1
	b	3.7	3.4	3.5	3.2
IF	L	41.5	44.0	44.1	44.9
	a	13.0	12.2	12.0	10.7
	b	3.5	3.5	3.7	3.4
DWW	L	41.9	44.0	43.4	43.8
	a	13.6	12.7	11.6	10.2
	b	3.6	3.6	3.5	3.1
DCW	L	42.1	43.5	43.3	44.5
	a	14.1	13.3	11.9	10.4
	b	3.8	3.7	3.5	3.3
CW	L	41.8	43.6	41.9	43.2
	a	14.8	13.0	12.5	10.7
	b	4.0	3.8	3.7	3.6
Prob.	L	0.91	0.93	0.16	0.42
	a	0.37	0.38	0.44	0.80
	b	0.35	0.24	0.61	0.07

No differences due to lighting system. ($P > 0.05$).

[a]See Table 1.

Table 6. Display lighting effects on PVC packaged pork longissimus L, a and b value,Illuminant C.

Lighting	Hunter	Display day			
system[a]	value	0	1	3	5
N	L	41.5	41.8	40.5	43.6
	a	7.7	7.0	6.5	5.0
	b	7.5	7.3	6.9	6.7
GWS	L	41.8	41.7	42.1	43.0
	a	6.8	6.5	5.9	5.0
	b	7.1	6.5	7.0	6.1
NAFA	L	41.2	42.4	41.6	42.6
	a	7.1	6.5	5.7	4.8
	b	6.9	6.4	6.5	6.0
IF	L	40.3	42.8	43.0	43.9
	a	6.7	6.3	5.9	5.1
	b	6.4	6.3	6.9	6.4
DWW	L	40.7	42.8	42.3	42.8
	a	6.9	6.4	5.7	5.0
	b	6.8	6.6	6.5	5.9
DCW	L	40.7	42.2	41.7	43.4
	a	7.2	6.8	6.0	5.0
	b	7.0	6.9	6.5	6.1
CW	L	40.4	42.4	40.6	42.6
	a	7.6	6.6	6.4	5.4
	b	7.4	6.9	6.8	6.7
Prob.	L	0.93	0.91	0.15	0.68
	a	0.34	0.59	0.18	0.65
	b	0.41	0.21	0.71	0.09

No differences due to lighting system ($P > 0.05$).

[a]See Table 1.

Table 7. Display lighting effects on PVC packaged pork longissimus L*, a* and b*[a] value, Illuminant A.

Lighting	Hunter	Display day			
system[b]	value	0	1	3	5
N	L*	49.7	50.1	48.7	51.5
	a*	16.8	15.5	14.5	12.1
	b*	10.4	9.9	9.6	8.8
GWS	L*	50.0	49.9	50.2	51.0
	a*	15.2	14.3	13.7	11.7
	b*	9.4	8.7	9.4	8.0
NAFA	L*	49.3	50.5	49.6	50.5
	a*	15.7	14.4	13.3	11.6
	b*	9.4	8.5	8.7	7.8
IF	L*	48.4	51.0	51.0	51.9
	a*	14.8	13.7	13.6	12.1
	b*	8.7	8.4	9.2	8.3
DWW	L*	48.6	51.0	50.3	50.7
	a*	15.6	14.3	13.2	11.6
	b*	9.3	8.8	8.6	7.7
DCW	L*	48.8	50.5	49.8	51.3
	a*	16.0	14.9	13.5	11.8
	b*	9.5	9.3	8.8	7.9
CW	L*	48.4	50.6	48.7	50.6
	a*	16.9	14.7	14.3	12.7
	b*	10.2	9.3	9.3	8.9
Prob.	L*	0.92	0.94	0.24	0.68
	a*	0.45	0.34	0.29	0.42
	b*	0.40	0.16	0.48	0.09

No differences due to lighting system ($P > 0.05$).

[a]CIE (1976).

[b]See Table 1.

Table 8. Display lighting effects on PVC packaged pork longissimus L*, a* and b*[a] value, Illuminant C.

Lighting system[b]	Hunter value	Display day 0	1	3	5
N	L*	48.2	48.7	47.4	50.4
	a*	9.6	8.6	8.1	6.2
	b*	10.8	10.2	9.8	9.1
GWS	L*	48.6	48.6	48.9	49.9
	a*	8.4	8.0	7.4	6.2
	b*	9.8	8.9	9.7	8.3
NAFA	L*	47.9	49.3	48.5	49.4
	a*	8.8	8.0	7.2	6.1
	b*	9.7	8.7	9.0	8.1
IF	L*	47.1	49.8	49.7	50.8
	a*	8.3	7.7	7.3	6.3
	b*	8.9	8.6	9.5	8.6
DWW	L*	47.3	49.7	49.2	49.7
	a*	8.7	7.9	7.1	6.1
	b*	9.7	9.0	8.9	7.9
DCW	L*	47.5	48.8	48.6	50.4
	a*	8.9	8.4	7.4	6.2
	b*	9.9	9.5	9.0	8.2
CW	L*	46.9	49.3	47.4	49.5
	a*	9.6	8.1	8.0	6.7
	b*	10.8	9.6	9.4	9.1
Prob.	L*	0.93	0.88	0.32	0.68
	a*	0.41	0.54	0.23	0.66
	b*	0.46	0.14	0.63	0.08

No differences due to lighting system ($P > 0.05$).

[a]CIE (1976).

[b]See Table 1.

Table 9. Display lighting effects on PVC packaged pork longissimus %R 630 - %R 580, %R 610 - %R 580.

Lighting system[a]	Display day 0	1	3	5
		(%R 630 - %R 580)		
N	14.4	13.0	11.0	9.6
GWS	13.3	11.9	10.9	9.2
NAFA	13.5	12.1	10.4	8.8
IF	12.6	11.8	11.2	9.8
DWW	13.0	12.2	10.7	9.1
DCW	13.7	12.7	10.8	9.5
CW	13.9	12.4	10.9	9.7
Prob.	0.18	0.50	0.82	0.24
		(%R 610 - %R 580)		
N	12.3	11.4	9.8	8.6
GWS	11.4	10.4	9.8	8.4
NAFA	11.6	10.6	9.4	8.0
IF	10.8	10.4	10.1	9.0
DWW	11.0	10.7	9.6	8.2
DCW	11.6	11.1	9.7	8.6
CW	11.7	10.7	9.7	8.7
Prob.	0.27	0.52	0.88	0.27

No differences due to lighting system ($P > 0.05$).

[a]See Table 1.

Table 10. Display lighting effects on PVC packaged pork longissimus metmyoglobin(MMb) and oxymyoglobin(MbO)

Lighting system[a]	Display day 0	1	3	5
		(%MMb)		
N	18.1	18.4	24.9	27.5
GWS	18.2	20.1	24.4	28.6
NAFA	17.4	20.0	25.4	28.6
IF	16.0	22.3	23.6	27.3
DWW	18.4	20.4	24.5	27.0
DCW	17.1	19.4	22.2	27.3
CW	17.3	21.1	24.9	27.2
Prob.	0.60	0.28	0.96	0.61
		(%MbO)		
N	56.5	53.2	49.5	47.6
GWS	54.6	50.8	49.4	46.3
NAFA	55.0	49.3	48.3	44.0
IF	53.6	53.4	51.5	46.5
DWW	54.6	50.9	50.0	46.7
DCW	54.6	52.8	48.8	46.5
CW	55.2	51.0	49.1	45.9
Prob.	0.77	0.20	0.11	0.17

No differences due to lighting system ($P > 0.05$).

[a]See Table 1.

Table 11. Display lighting effects on PVC packaged pork mean TBA value (ug malonaldehyde/g) after 5 day display.

Lighting system[a]	TBA value
N	0.04
GWS	0.05
NAFA	0.16
IF	0.04
DWW	0.05
DCW	0.04
CW	0.05
Prob.	0.19

[a]See Table 1.

No differences due to lighting system ($P > 0.05$).

Table 12. Display lighting effects on vacuum packaged pork longissimus L, a and b value, Illuminant A.

Lighting	Hunter	Display day			
system[a]	value	0	7	14	21 [b]
N	L	43.1	45.4	43.3	39.4
	a	10.0	10.1	10.2	9.5
	b	1.3	1.1	1.2	0.6
GWS	L	43.6	45.1	43.3	38.7
	a	10.3	9.6	9.6	9.7
	b	1.3	0.9	1.1	0.8
NAFA	L	44.2	45.7	43.3	39.4
	a	10.9	10.2	10.5	10.2
	b	1.6	1.3	1.4	0.7
IF	L	44.6	45.1	44.8	42.3
	a	10.4	10.1	10.1	10.0
	b	1.4	1.1	1.3	1.2
DWW	L	44.0	44.3	43.3	39.7
	a	10.1	10.0	10.2	8.7
	b	1.4	1.1	1.3	0.8
DCW	L	46.0	44.3	43.6	39.8
	a	11.1	9.9	10.2	8.9
	b	1.7	1.1	1.3	0.8
CW	L	44.8	44.3	43.4	40.3
	a	11.3	9.7	10.2	9.1
	b	1.5	0.9	1.2	0.7
Prob.	L	0.35	0.56	0.91	0.48
	a	0.35	0.38	0.52	0.11
	b	0.17	0.37	0.41	0.33

No differences due to lighting system ($P > 0.05$).

[a]See Table 1.

[b]Day 21 data, 3 samples only.

Table 13. Display lighting effects on vacuum packaged pork longissimus L*, a* and b*[a] value, Illuminant A.

Lighting	Hunter	Display day			
system[b]	value	0	7	14	21 [c]
N	L*	50.1	52.4	50.4	46.3
	a*	11.4	11.4	11.6	11.1
	b*	2.9	2.6	2.7	1.4
GWS	L*	50.6	52.1	50.2	45.4
	a*	11.6	10.8	11.0	11.4
	b*	2.9	2.1	2.6	1.8
NAFA	L*	51.2	52.1	50.3	46.3
	a*	12.4	11.5	12.0	11.9
	b*	3.9	2.9	3.2	1.6
IF	L*	50.9	52.1	51.8	49.4
	a*	11.8	11.3	11.4	11.4
	b*	3.2	2.6	3.1	2.7
DWW	L*	51.6	51.2	50.3	46.5
	a*	11.3	11.4	11.6	10.3
	b*	2.9	2.5	3.1	1.6
DCW	L*	53.1	51.2	50.6	46.8
	a*	12.4	11.3	11.6	10.5
	b*	3.9	2.5	3.0	1.8
CW	L*	51.9	51.3	50.5	47.2
	a*	12.7	11.0	11.6	10.7
	b*	3.5	2.1	2.8	1.6
	L*	0.38	0.45	0.91	0.47
	a*	0.36	0.46	0.57	0.13
	b*	0.34	0.36	0.35	0.33

No differences due to lighting system ($P > 0.05$).

[a]CIE (1976).

[b]See Table 1.

[c]Day 21 data, 3 samples only.

Table 14. Display lighting effects on vacuum packaged pork longissimus L, a and b value, Illuminant C.

Lighting	Hunter	Display day			
system[a]	value	0	7	14	21 [b]
N	L	42.4	44.7	42.6	38.8
	a	4.0	4.0	4.1	4.2
	b	3.6	3.6	3.5	2.2
GWS	L	42.9	44.4	42.6	38.0
	a	4.2	3.8	3.6	4.5
	b	3.7	3.1	3.7	2.4
NAFA	L	43.4	45.1	42.5	38.7
	a	4.6	4.0	4.4	4.8
	b	4.3	3.8	3.8	2.3
IF	L	43.8	44.4	44.0	41.6
	a	4.3	4.0	4.0	4.3
	b	3.5	3.9	3.9	3.2
DWW	L	43.3	43.6	42.5	39.1
	a	4.1	4.1	4.2	3.8
	b	3.8	3.4	3.8	2.4
DCW	L	45.0	43.6	42.9	39.2
	a	4.4	4.0	4.0	3.9
	b	4.5	3.4	3.8	2.5
CW	L	44.0	43.2	42.6	39.6
	a	4.7	3.8	4.0	4.0
	b	4.1	3.1	3.7	2.3
Prob.	L	0.37	0.32	0.91	0.48
	a	0.52	0.87	0.39	0.28
	b	0.23	0.37	0.95	0.37

No differences due to lighting system ($P > 0.05$).

[a]See Table 1.

[b]Day 21 data, 3 samples only.

Table 15. Display lighting effects on vacuum packaged pork longissimus L*, a* and b*[a] value, Illuminant C.

Lighting	Hunter	Display day			
system[b]	value	0	7	14	21 [c]
N	L*	49.4	51.7	49.6	45.7
	a*	5.0	4.9	5.1	5.4
	b*	4.8	4.6	4.6	3.0
GWS	L*	49.9	51.5	49.6	44.7
	a*	5.2	4.7	4.5	5.8
	b*	4.8	4.0	4.7	3.1
NAFA	L*	49.5	52.2	49.5	45.5
	a*	5.7	4.9	5.5	6.1
	b*	5.7	4.9	5.1	3.1
IF	L*	50.8	51.4	51.1	48.6
	a*	5.3	4.9	4.9	5.4
	b*	5.1	4.5	5.0	4.3
DWW	L*	50.2	50.5	49.5	45.9
	a*	5.0	5.1	5.1	4.8
	b*	5.0	4.4	5.0	3.1
DCW	L*	46.2	50.5	49.9	46.1
	a*	5.4	4.9	5.0	4.9
	b*	5.8	4.4	5.0	3.4
CW	L*	51.0	50.6	49.7	46.6
	a*	5.8	4.7	5.0	5.1
	b*	2.2	0.40	0.85	0.36
Prob.	L*	0.33	0.48	0.91	0.48
	a*	0.56	0.89	0.45	0.29
	b*	0.34	0.36	0.35	0.33

No differences due to lighting system ($P > 0.05$).

[a]CIE (1976).

[b]See Table 1.

[c]Day 21 data, 3 samples only.

Table 16. Display lighting effects on vacuum packaged pork longissimus %R 630 - %R 580 and %R 610 - %R 580.

Lighting system[a]	Display day 0	7	14	21[b]
		(%R 630 - %R 580)		
N	10.0	10.6	10.0	8.6
GWS	10.4	9.9	9.5	8.9
NAFA	10.9	10.7	10.3	9.3
IF	10.7	10.4	10.2	10.0
DWW	10.4	10.3	10.1	8.3
DCW	11.6	10.2	10.1	8.3
CW	11.5	10.1	10.1	8.8
Prob.	0.47	0.34	0.67	0.13
		(%R 610 - %R 580)		
N	7.1	7.6	7.3	6.3
GWS	7.5	7.2	6.9	6.2
NAFA	7.8	7.7	7.6	6.7
IF	7.6	7.5	7.5	7.1
DWW	7.4	7.3	7.4	6.1
DCW	8.0	7.2	7.2	6.0
CW	8.1	7.1	7.3	6.3
Prob.	0.17	0.14	0.57	0.12

No differences due to lighting system ($P > 0.05$).

[a]See Table 1.

[b]Day 21 data, 3 samples only.

Table 17. Display lighting effects on vacuum packaged pork longissimus metmyoglobin(MMb) and deoxymyoglobin(Mb)

Lighting system[a]	Display day 0	7	14	21[b]
		(%MMb)		
N	25.3	24.6	24.0	22.7
GWS	24.7	25.1	23.8	23.1
NAFA	26.0	25.1	25.1	21.5
IF	26.0	24.7	25.3	23.3
DWW	25.6	25.9	25.4	22.4
DCW	27.3	25.6	24.7	24.2
CW	25.5	25.0	24.2	22.6
Prob.	0.61	0.48	0.73	0.45
		(%Mb)		
N	82.4	87.5	86.0	83.6
GWS	84.0	86.4	85.5	79.1
NAFA	81.7	87.1	82.7	83.1
IF	83.1	86.5	83.3	75.3
DWW	82.7	86.0	80.7	75.2
DCW	86.2	87.3	86.1	77.0
CW	87.6	87.2	86.5	76.8
Prob.	0.94	0.68	0.33	0.21

No differences due to lighting system ($P > 0.05$).

[a]See Table 1.

[b]Day 21 data, 3 samples only.

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THE EFFECT OF DISPLAY LIGHTING ON UNFROZEN PORK COLOR

by

CHING-YAU SIMON HUNG

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AN ABSTRACT OF A THESIS

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ABSTRACT

Light may play a major role in the perception of consumers for pork quality and discolored pork is often rejected. The objective of this study was to evaluate the effect of seven lighting systems on fresh pork longissimus color and rancidity development during display. Seven lighting systems [Natural (N);Grolux Wide Spectrum (GWS); NAFA; Incandescent Fluorescent (IF); Deluxe Warm white (DWW); Deluxe Cool White (DCW); Cool White (CW)] and two kinds of packaging [(vacuum (VAC) in oxygen-barrier film) and polyvinylchloride (PVC, oxygen-permeable)] were compared under 1076 lux (100 ft - c) at 2 to 3 C, measuring at 0, 1, 3, 5 days of PVC packaged display and 0, 7, 14, 21 days of VAC packaged display. Chops (14) from each of seven loins were randomly assigned to each light and these color traits were measured: % metmyoglobin (MMb), % oxymyoglobin (MbO), % deoxymyoglobin (Mb), reflectance difference at 630 and 580 nm (R 630 - R 580), and at 610 and 580 nm (R 610 - R 580), HunterLab values, and visual score taken under display light and common light. The visual scores of PVC and VAC packaged pork under display light indicated effects ($P < 0.01$) from lighting systems throughout display as NAFA lighting resulted in brighter pink color than other lights except GWS, while CW resulted in darker color, but no difference ($P > W.05$) when scored under common light for PVC packaged

pork. Although the visual scores under common light for VAC display were slightly different ($P < 0.05$) in day 0 and 14, the conclusion could still be made that display lighting affects pork color but the effect is largely due to spectral energy distribution of the light source and no apparently different photochemical effect among seven display lights, because these was no difference ($P > 0.05$) for HunterLab ILL A and C (L, L*, a, a*, b, b*); % R 630 - % R 580; % of MMb, Mb and MbO. No differences between light treatments existed for the TBA rancidity test.